DSN Radio Science System, Mark III-80

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This article describes the key characteristics, functional operation, and functional requirements of the DSN Radio Science System, Mark III-80. Particularly emphasized is "medium bandwidth" capability, which will enable support of the Voyager Saturn Ring Experiment in November 1980.

I. Introduction

The DSN Radio Science System, Mark III-80, is one of eight DSN Data Systems which provide major data types and functional capabilities to the flight projects. In the broadest sense, the DSN Data Systems encompass the equipment, software, personnel, documentation, procedures, and resources necessary to deliver the required data to the flight projects. The Radio Science System was brought into existence on February 4, 1977, at which time the system requirements were reviewed and accepted by the Radio Science Review Board. The February 4, 1977 Radio Science Requirements Review has been described by Mulhall (Ref. 1).

The DSN Radio Science System, Mark III-78, configuration has been described in detail in a previous report (Ref. 2). The major difference between the Mark III-78 and Mark III-80 configurations is the addition of the capability necessary to support the Voyager Saturn Ring Experiment. Hence, it is the new capabilities being implemented in support of the Saturn Ring Experiment which will serve as the focus of this article.

A. Radio Science System Definition

The DSN Radio Science System is defined as follows:

> The DSN Radio Science System generates radio science data (digitized amplitude samples) from spacecraft signals which are both left circularly polarized (LCP) and right circularly polarized (RCP) and are at S-band and X-band frequencies. The radio science data bandwidth is reduced in either real time or nonreal time via differencing with a predicted signal profile. Bandwidth-reduced radio science data are delivered to the project via computer-compatible magnetic tape.
>
> The DSN Radio Science System additionally provides real-time graphical displays of both radio metric and radio science data.

Figure 1 illustrates the Radio Science System functions and interfaces. The Radio Science System functional block diagram is shown in Fig. 2. Note that Fig. 2 also includes DSN Tracking System functional capabilities, which deliver the closed-loop radio science (radio metric) data. Finally, Fig. 3 illustrates the Radio Science System functions and data flow.

B. Radio Science System Key Characteristics

The key characteristics of the DSN Radio Science System, Mark III-80, are as follows:

(1) Acquires left and right circularly polarized spacecraft signals at S- and X-band frequencies.

(2) Digitizes and bandwidth-reduces up to four open-loop receiver channels simultaneously by means of an automatically controlled programmed oscillator.

(3) Digitizes and records wide bandwidth open-loop receiver output.

(4) Generates programmed oscillator frequency predictions that incorporate refractive effects due to planetary atmospheres.

(5) Performs real-time system performance monitoring and provides system performance data in real time to the project.

(6) Transmits radio science data from the Deep Space Stations (DSSs) to the Network Operations Control Center (NOCC) via Wideband Data Line (WBDL).

(7) Performs nonreal-time bandwidth reduction of wide bandwidth radio science data.

(8) Provides wide bandwidth backup of all unique radio science events.

(9) Provides radio science data to the project via computer-compatible magnetic tape.

C. Flight Project Users of the DSN Radio Science System

Flight projects with active spacecraft supported by the Radio Science System are:

(1) Voyager

(2) Pioneer Venus

(3) Pioneer Saturn

(4) Helios

(5) Viking

New or anticipated flight projects that can be expected to utilize the Radio Science System are:

(1) Solar Polar

(2) Galileo

(3) VOIR

(4) Solar Probe

II. Radio Science System Functional Description

The DSN Radio Science System, Mark III-80, provides four major functional capabilities:

(1) *Wide Bandwidth Recording and Subsequent Nonreal-Time Bandwidth Reduction.* Wide bandwidth is defined as being greater than 500 kHz. Wide bandwidth recording and subsequent nonreal-time bandwidth reduction capability was initially implemented to support the Pioneer Venus DLBI Experiment, and since has been utilized to provide a wide bandwidth backup for occultation operations.

(2) *Real-Time Bandwidth Reduction*[1] (*Narrow/Very Narrow Bandwidth*). Narrow bandwidth is defined as being between 1 kHz and 50 kHz, while very narrow bandwidth is defined as being less than 1 kHz. Real-time bandwidth reduction is utilized in support of solar corona experiments (very narrow bandwidth) and planetary occultation experiments (narrow bandwidth).

(3) *Real-Time Bandwidth Reduction (Medium Bandwidth).* Medium bandwidth is defined as being between 50 kHz and 500 kHz. Real-time bandwidth reduction (medium bandwidth) capability will be used to support the Voyager Saturn Ring Experiment.

(4) *Real-Time System Performance Validation.* This capability provides graphical displays of both radio science and radio metric data to the Network Operations Control Team and the appropriate flight project.

Wide bandwidth recording and subsequent nonreal-time bandwidth reduction, real-time bandwidth reduction (narrow/very narrow bandwidth), and real-time system performance validation were described in detail in Ref. 2. A detailed functional description of real-time bandwidth reduction (medium bandwidth) is presented in Section III.

[1]The expression "real-time bandwidth reduction" is here defined as the process of programming the open-loop receiver local oscillator with frequency predictions, and subsequently filtering, digitizing, and recording a narrow baseband bandwidth containing the hetrodyned signal.

III. Real-Time Bandwidth Reduction (Medium Bandwidth) Functional Description

As previously described, real-time bandwidth reduction (medium bandwidth) capability is being implemented to support the Voyager Saturn Ring Experiment. The goals of the Saturn Ring Experiment are described by Eshleman et al. (Ref. 3) as follows:

> "The goals of these observations are to measure the complex (amplitude and phase) radio extinction and angular scattering function of the rings as a function of wavelength, polarization, and radial distance from Saturn. These observations would then be used to infer the first several moments of the ring particle size distribution, the total amount of material in the rings, the radial distribution of that material, and limits to possible particle shapes and constituents."

The functional description of real-time bandwidth reduction (medium bandwidth) is categorized below by subsystem functions.

A. The Network Operations Control Center (NOCC) Radio Science Subsystem (NRS)

The NRS provides two main functions during the Saturn Ring Experiment: Radio Science predictions and real-time system performance validation.

Radio science predictions are generated by the "POEAS" software program following receipt from the flight project of a spacecraft state vector. The POEAS program generates frequency-independent observables which have been corrected for planetary atmospheric refraction. These data are written on a magnetic tape (polynominal coefficient tape or PCT) and are passed to the NOCC Support Subsystem.

In performing real-time system performance validation, digital data originating from the (DSS) Spectral Signal Indicator (SSI) are reconstructed into spectral displays and are provided on digital television in NOCC and the project radio science area via the NOCC Display Subsystem.

B. The NOCC Support Subsystem (NSC)

The NSC utilizes the software program "PREDIK" to generate frequency-dependent radio science predictions for the Deep Space Stations (DSSs). Inputs are the PCT from the NRS and spacecraft frequencies from the flight project. The output is radio science predictions which are transmitted via High-Speed Data Line (HSDL) to the DSS Radio Science Subsystem (DRS).

C. The DSS Antenna Microwave Subsystem (UWV)

The UWV provides S- and X-band signals that are both right circularly polarized (RCP) and left circularly polarized (LCP) via an orthomode polarizer. The UWV functional block diagram is seen in Fig. 4.

D. The DSS Receiver-Exciter Subsystem (RCV)

The RCV provides two main functions during the Saturn Ring Experiment: acquisition of four signals simultaneously and real-time spectral analysis of a reconstructed analog signal received from the DRS.

The RCV utilizes the four-channel medium bandwidth Multimission Open-Loop Receiver (MMR) to acquire the four signals (permutations of S- and X-band, and LCP and RCP) simultaneously. The MMR contains a programmed oscillator which heterodynes the signals down from S- and X-band to medium bandwidth. The programmed oscillator is driven by a (predicted) frequency profile provided by the DRS. The output medium bandwidth signals are appropriately filtered and provided to the Medium Bandwidth Converter Subassembly of the DRS. The programmed oscillator frequency (initially at 41 MHz) is heterodyned down to the MHz level and provided to the DRS for recording. A functional block diagram of the MMR is seen in Fig. 5.

During MMR operations, the RCV is provided a reconstructed medium bandwidth signal by the DRS. This signal is analyzed by the Spectral Signal Indicator (SSI), with the output being real-time spectrum displays. These displays are provided to the DRS in digital form for eventual display via the NRS.

E. The DSS Radio Science Subsystem (DRS)

The DRS has the major functions of providing the predicted doppler profile to the MMR programmed oscillator and the subsequent digitization and recording of the receiver medium bandwidth output signals.

Radio science predictions in the form of frequency and time pairs are received by the Occultation Data Assembly (ODA). These are converted to an initial frequency and subsequent frequency rates and provided to the MMR Programmed Oscillator Control Assembly.

The four signals output by the MMR are digitized by the Medium Bandwidth Converter Subassembly of the ODA and recorded on the Digital Recording Assembly (DRA). The

MMR provides the down-converted programmed oscillator frequency to the Frequency Monitor Subassembly (FMS), where it is counted and recorded by the ODA. The ODA also records the frequency predictions provided to the programmed oscillator, as well as the commanded programmed oscillator frequencies on integer second intervals.

A reconstructed analog signal is provided to the SSI of the RCV, and the resulting digital spectrum data from the SSI are received by the ODA, and formatted for and transmitted via WBDL to NOCC.

The ODA provides real-time status, configuration, and alarm data locally via the DSS Monitor and Control Subsystem and via HSDL to the NOCC.

Subsequent to the generation of radio science data, the ODA and DRA recorded tapes are shipped to the Network Radio Science Subsystem (WRS) for further processing. A functional block diagram of the DRS is provided in Fig. 6, while Fig. 7 provides a DRA functional block diagram.

F. The Network (NWK) Radio Science Subsystem (WRS)

The WRS receives the DRA recorded data from the DSS, plays back the DRA recorded data and rewrites (one signal per pass through) the digitized data onto computer-compatible tapes. These tapes plus the ODA recorded tapes, which contain the programmed oscillator information, constituting the sum total of radio science data, are then delivered to the flight project.

IV. Real-Time Bandwidth Reduction (Medium Bandwith) Functional Requirements

The functional requirements for real-time bandwidth reduction (medium bandwidth) are presented below.

A. Radio Frequency Bands

The Radio Science System shall acquire spacecraft signals at S- and X-bands.

B. Signal Polarization

Medium bandwidth requirements are for simultaneous reception of both RCP and LCP at both S- and X-bands.

C. System Noise Temperature

(1) Calibration precision: 1%

(2) Accuracy at 0.1-second sample interval: 2%

(3) Stability over one pass: 10%

D. Radio Frequency Phase Stability

The Radio Science System shall provide a highly phase-stable radio frequency (RF) signal acquisition capability; specific medium bandwidth requirements are stated as follows:

(1) The maximum deviation after calibration from an ideal linear phase response shall be:

(a) Single S-band channel: 36° or less

(b) Single X-band channel: 132° or less

(c) Differenced S - X channel: S-band minus 3/11 · X-band; less than 10°

(d) Differenced RCP minus LCP channels, at both S- and X-bands; less than 1°.

(2) Phase response measurement conditions are:

(a) Signal measured at the filtered receiver output and across the spanned -1 dB bandwidth

(b) 100-second measurement period

E. Programmed Oscillator Control

The receiver first local oscillator shall be automatically controlled to follow a predicted frequency versus time profile.

F. Output Bandwidths

Specific medium bandwidth requirements for the output ("sampled") bandwidth are as follows:

(1) 50 kHz for LCP and RCP S-band

(2) 150 kHz for LCP and RCP X-band

G. Radio Frequency Amplitude Response

The multimission Radio Science System amplitude response requirements are:

(1) The 100 percent bandwidth shall be defined as the "sampled" bandwidth.

(2) The "usable" bandwidth, defined by the -1 dB points, shall be ⩾83 percent of the sampled bandwidth.

(3) ±37 percent of the (sampled) bandwidth relative to the bandpass center shall have an amplitude ripple of less than ±0.2 dB.

(4) The "rejection" bandwidth, defined by the -23 dB points, shall be ⩽117 percent of the sampled bandwidth.

H. Analog to Digital (A-D) Conversion

Analog to digital conversion shall be performed with $\geqslant$ 8-bit quantization.

I. Timing Information

Data shall be time-tagged to the following specifications:

(1) *Time Offset*. Time tag offset from station time shall be less than 10 microseconds.

(2) *Sampling Rate Accuracy*. Sampling rate accuracy ($\Delta F/F$) shall be better than $10^{-5} \cdot (\text{bandwidth})^{-1}$.

(3) *Sampling Jitter*. Sampling jitter shall be less than $(2^8 \cdot \text{bandwidth})^{-1}$.

J. Programmed Oscillator Frequency Recording

Programmed oscillator frequency output shall be time-tagged and recorded as follows:

(1) *Counted Frequency Recording*. The programmed oscillator frequency shall be counted and recorded at one-second intervals on the integer second.

(2) *Counted Frequency Accuracy*. The counted programmed oscillator frequency shall be accurate to 0.5 Hz at S-band (RMS)

(3) *Commanded Frequency Recording*. The commanded programmed oscillator frequency shall be recorded at one-second intervals on the integer second.

(4) *Predicted Frequency Recording*. The predicted programmed oscillator initial frequency and subsequent frequency rates shall be recorded.

K. Data Return

Data shall be provided to the flight project on computer-compatible tape.

V. Implementation Schedule

Medium bandwidth capability is required to be implemented at DSS 63 by April 1, 1980. Specific elements include:

(1) Medium bandwidth data handling (ODA, DRA)

(2) SSI remote display (SSI, ODA, NRS)

(3) Radio science data return via WBDL

(4) DRS-NRS interface via HSDL

(5) Medium bandwidth MMR

(6) X-band orthomode (UWV)

(7) Four channel wide bandwidth backup (RCV, DRA)

(8) Precision Power Monitor (PPM)

References

1. Mulhall, B. D. L., "DSN Radio Science System Description and Requirements," in *The Deep Space Network Progress Report 42-39*, pp. 119-129, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1977.

2. Berman, A. L., "DSN Radio Science System, Mark III-78," in *The Deep Space Network Progress Report 42-47*, pp. 4-13, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 15, 1978.

3. Eshleman, V. R., et al., "Radio Science Investigations with Voyager," *Space Science Reviews*, Vol. 21, 1977.

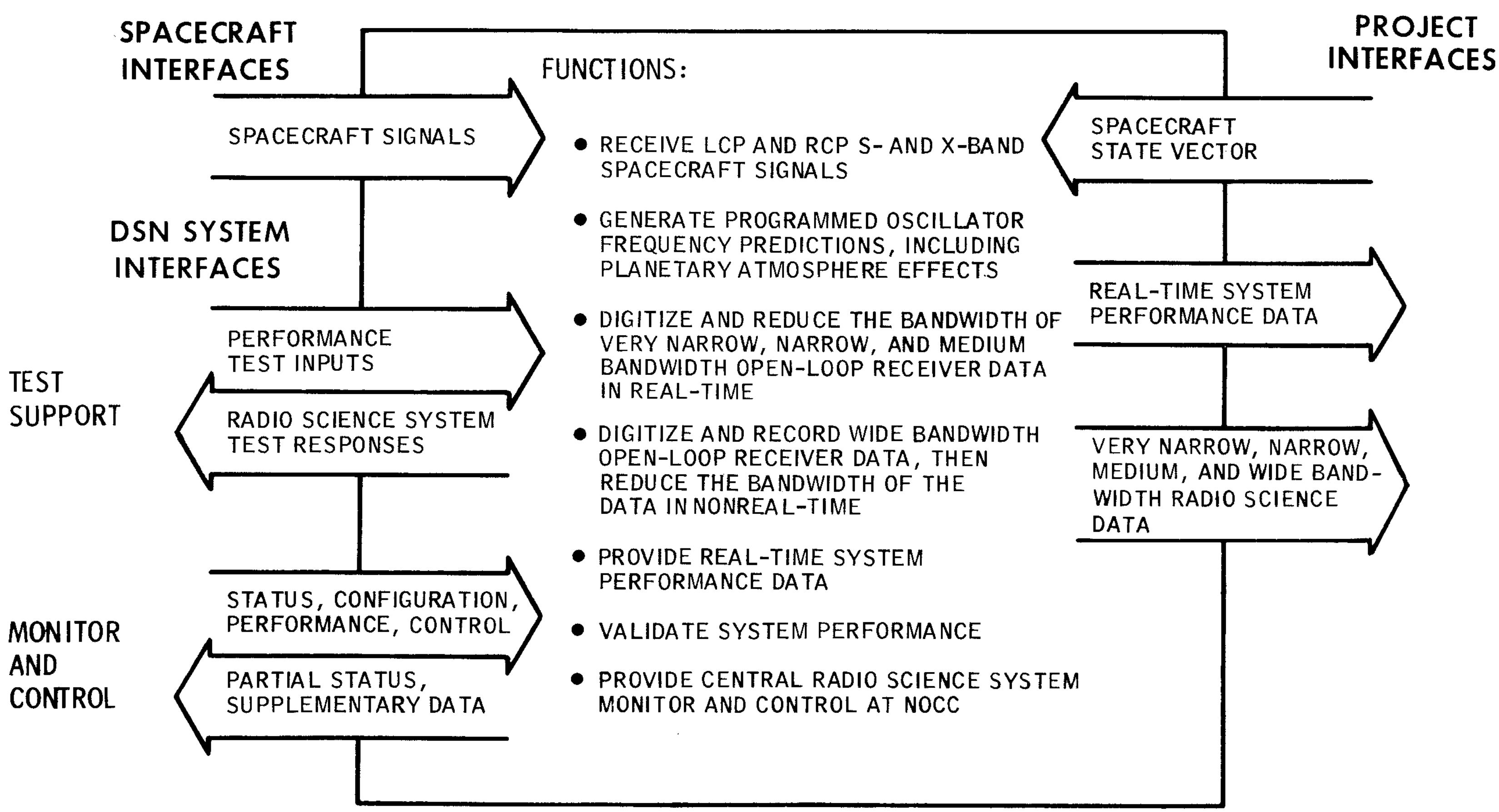

Fig. 1. Radio Science System, Mark III-80, functions and interfaces

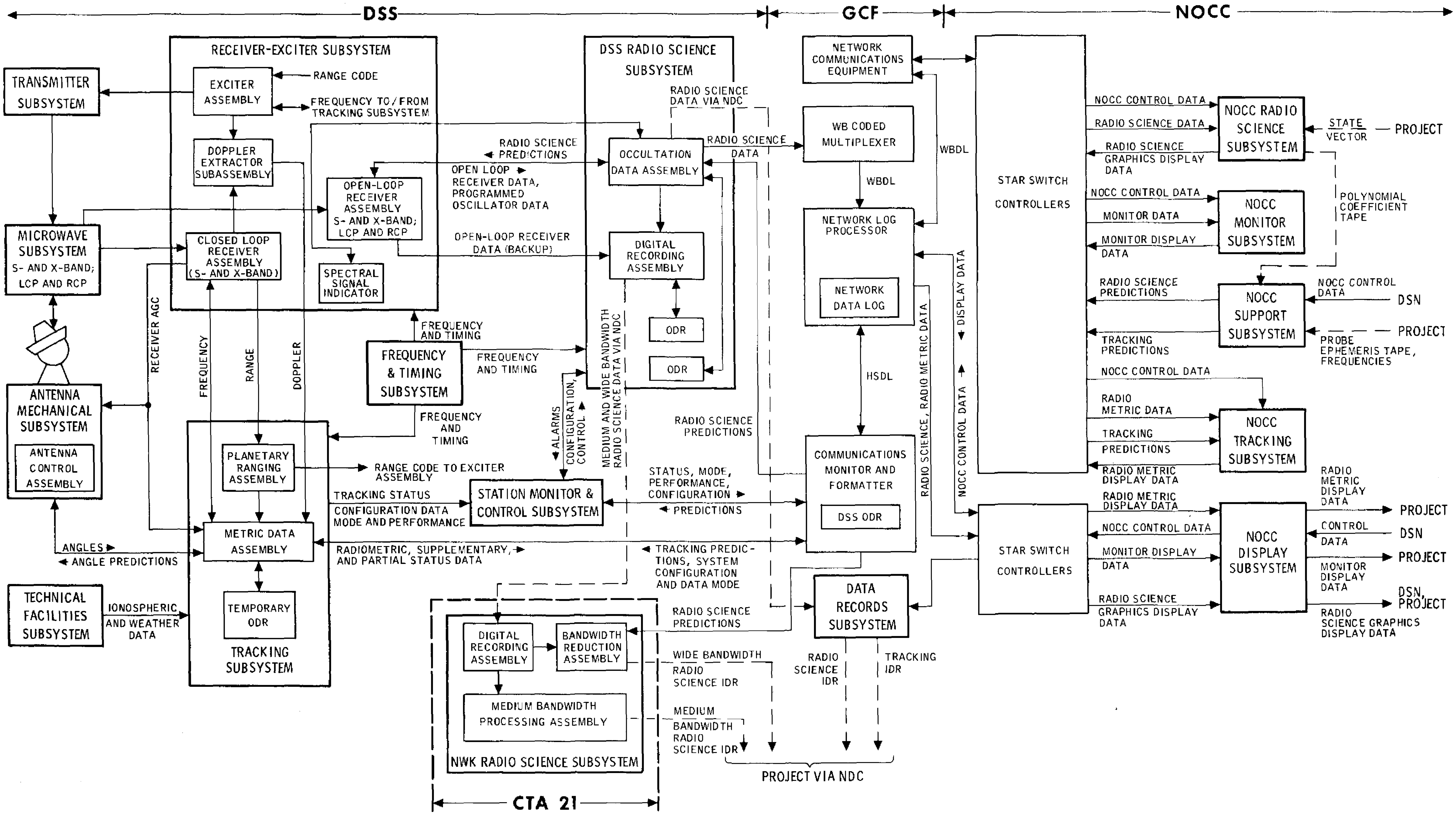

Fig. 2. Radio Science System, Mark III-80, functional block diagram

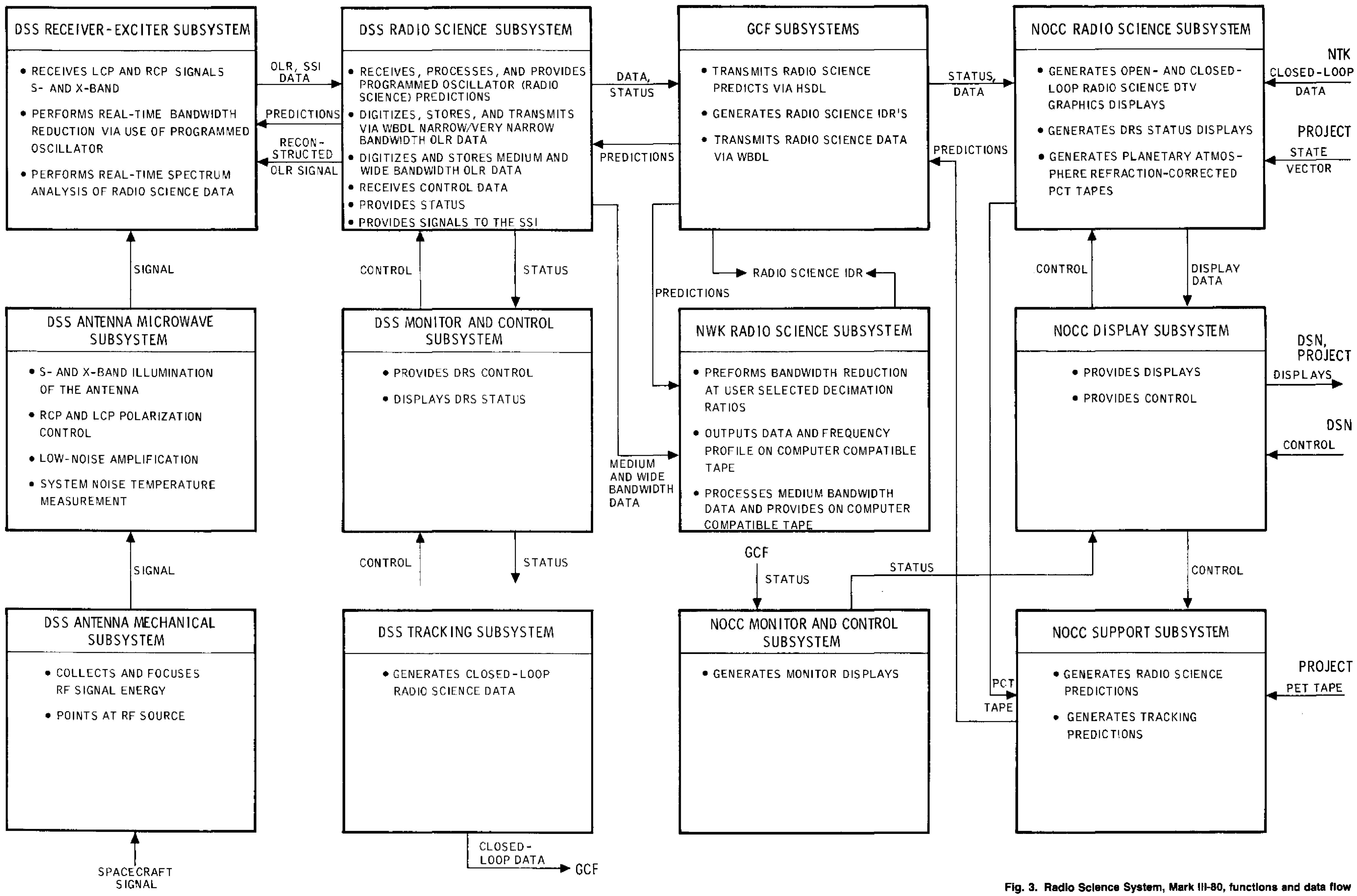

Fig. 3. Radio Science System, Mark III-80, functions and data flow

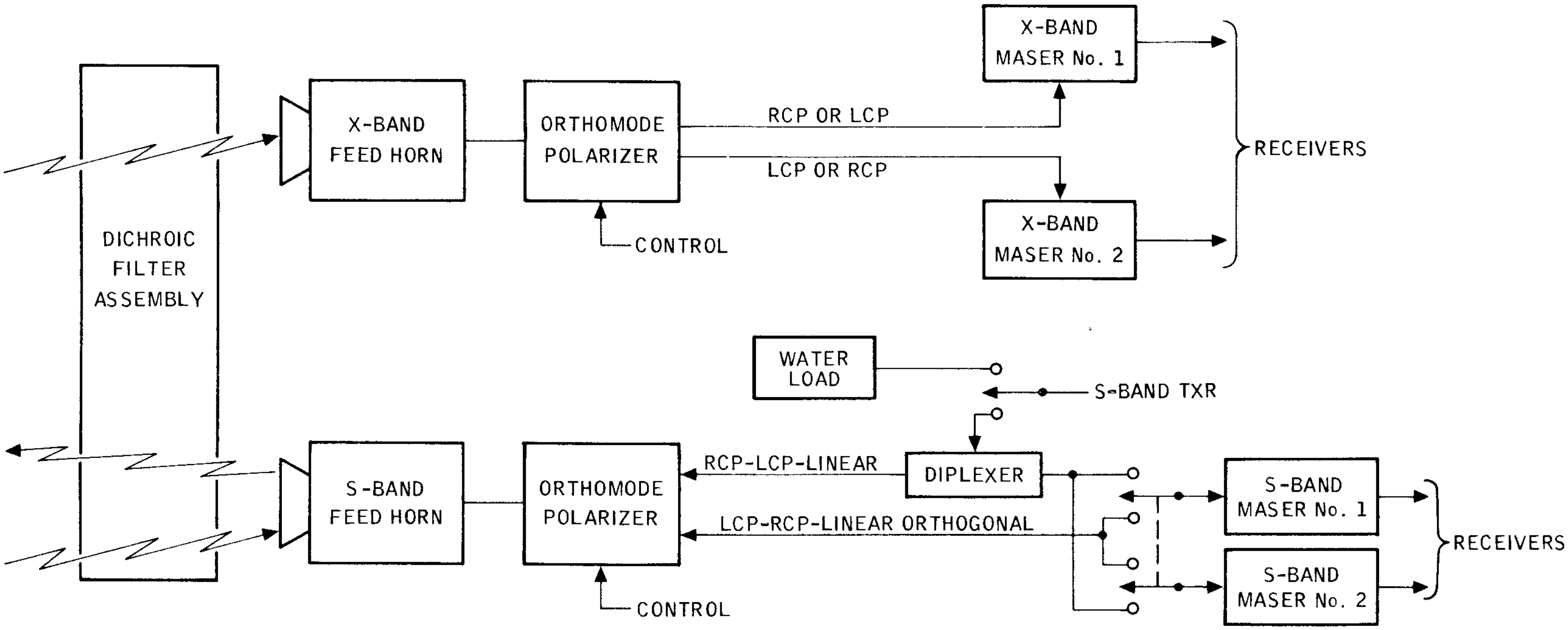

Fig. 4. DSS Antenna Microwave Subsystem functional block diagram—orthomode polarizer

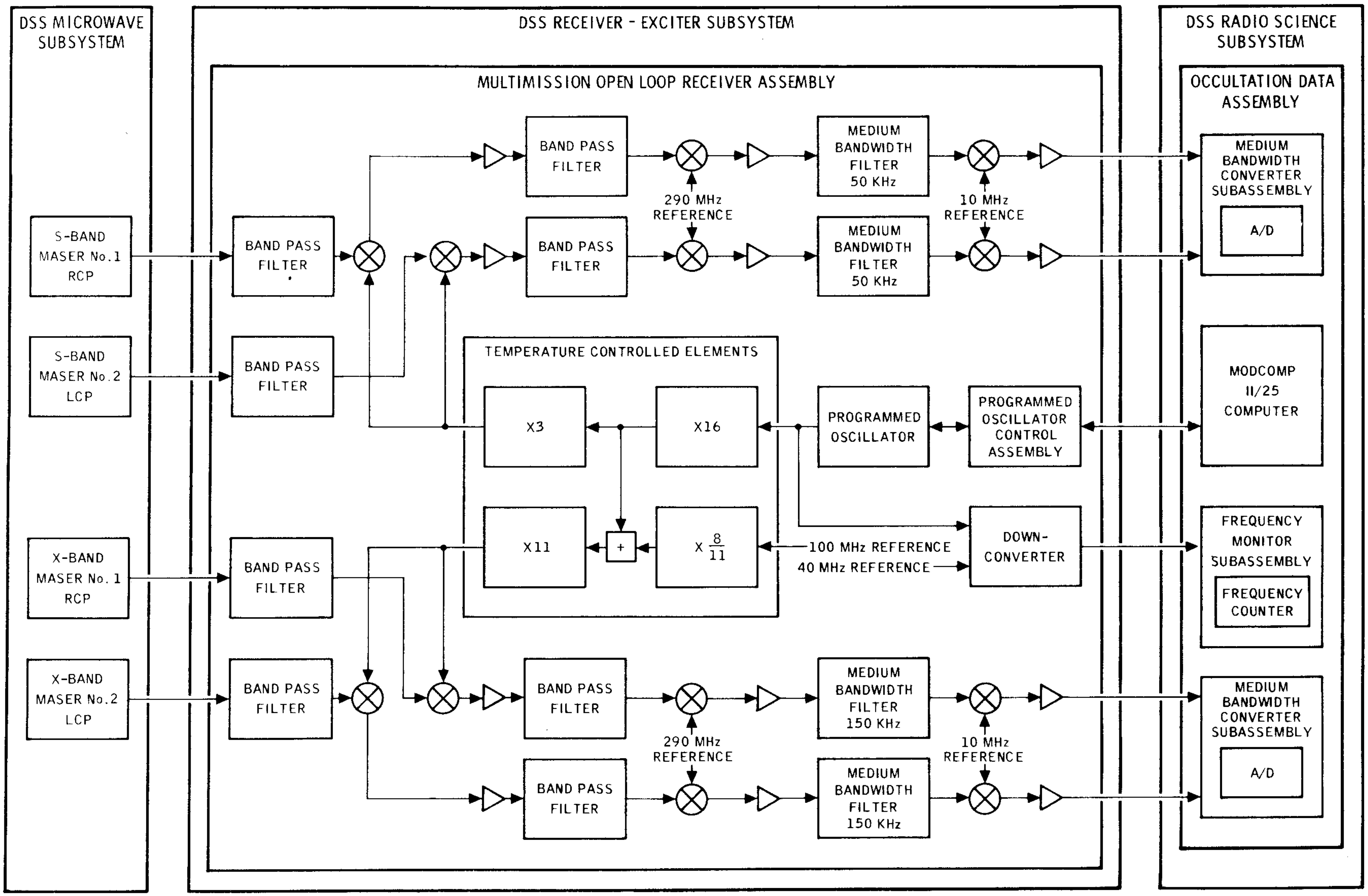

Fig. 5. DSS Receiver-Exciter Subsystem functional block diagram—Multimission Open-Loop Receiver (MMR)

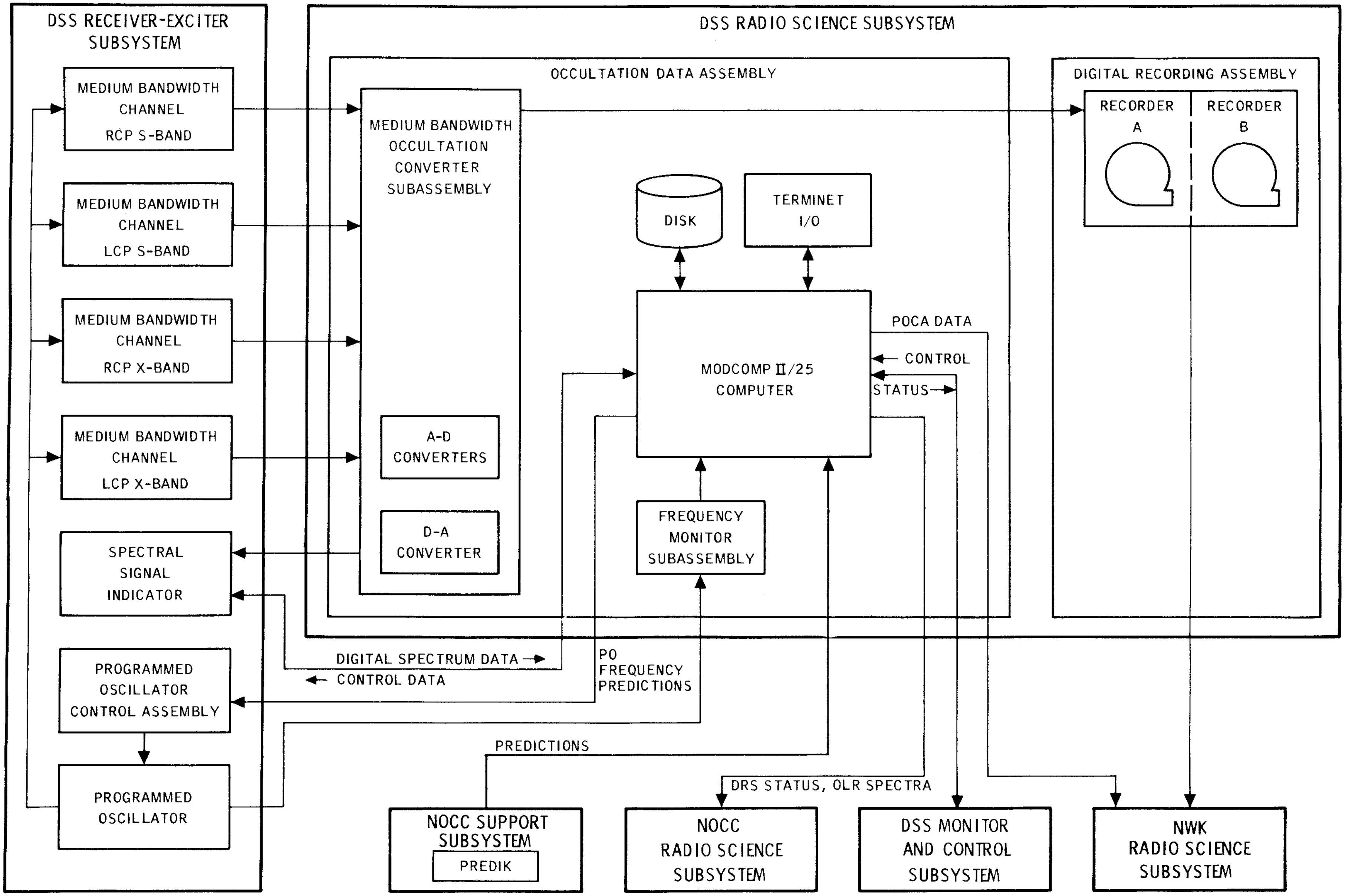

Fig. 6. DSS Radio Science Subsystem functional block diagram—medium bandwidth configuration

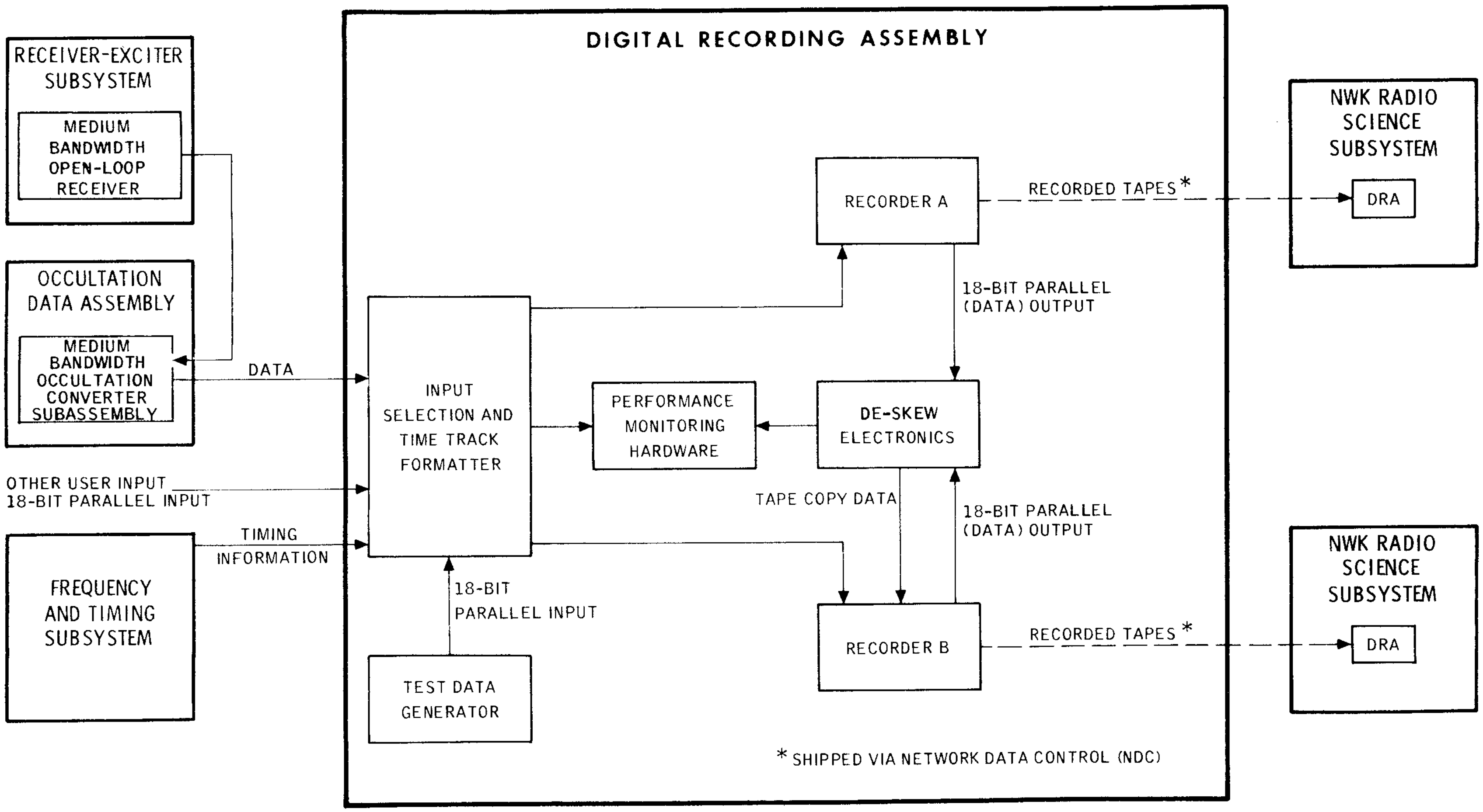

Fig. 7. Digital Recording Assembly functional block diagram—medium bandwidth configuration